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THE INTENSITY-FREQUENCY OF KANSAS WINDS

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In cooperation with Kansas Agricultural Experiment Station

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THE INTENSITY-FREQUENCY OF KANSAS WINDS[1]

By A. W. Zingg, project supervisor, Division of Erosion Control Practices, Research, Soil Conservation Service[2]

This report presents the results of frequency studies of wind movement in the central portion of the Great Plains region. The research is confined to the analysis of anemometer records for the months of April at 12 locations. It is further limited to periods of record for which each gage location is constant.

The writer has cited previously the adaptability of the frequency approach as a tool for making quantitative estimates of intense wind movements.[3] The need for such information as related to the problem of soil erosion by wind has also been discussed. The present work extends the application of this approach to the point where some generalization is possible. The study should be broadened eventually to include all records available in the High Plains area. Periods of wind movement, in addition to those occurring during the month of April, should be considered also. An endeavor of this scope is beyond the extent of resources available for the present.

PROCEDURE

Estimates of the recurrence of given climatological phenomena have been made by various methods. Where short-time records are used, no known method can yield frequency curves having the property of stability. The recognition of this limitation warrants the adoption of a simple method which yields reasonable results. After several procedures were tried, a simplified Gumbel method[4] described by Powell[5] was adopted for this particular study. This method was developed originally for the estimation of flood frequencies. It is applied here to wind movement with some simplification and with appropriate changes in the nomenclature.

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[1]Contribution from the Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kans., and the Soil Conservation Service, U. S. Department of Agriculture. Cooperative research in the mechanics of wind erosion.

[2]The author wishes to acknowledge gratefully the assistance of D. A. Russ, agricultural aid, who performed much of the detailed tabulation and calculation required for the study; also to thank personnel of the Weather Bureau, the Bureau of Plant Industry, Soils, and Agricultural Engineering, Soil Conservation Service--Research, and the Kansas Agricultural Experiment Station who made the data available and assisted in its assemblage.

[3]Zingg, A. W. A STUDY OF THE MOVEMENT OF SURFACE WIND. Agr. Engin. 30: 11-13, 19. 1949.

[4]Gumbel, E. J. THE RETURN PERIOD OF FLOOD FLOWS. Annals of Math. Statistics, 12 (2): 163-190. 1941.

[5]Powell, R. W. A SIMPLE METHOD OF ESTIMATING FLOOD FREQUENCY. Civ. Engin. 13: 105-107. 1943.

Briefly, the method used is based on two relationships:

$$V_m = V_A + S(0.7797y - 0.45005) \quad \text{and}$$

$$y = -\log_e \left[-\log_e(1 - 1/T) \right]$$

where V_m = *the wind velocity equaled or exceeded on the average of once in* T *years, where* T *is termed the recurrence interval.*

V_A = *average of the maximum wind velocities in miles per hour for a specific continuous period (based on one event per month of April per year =* V*).*

S = *standard deviation of maximum wind velocities for a specific continuous period, or*

$$S = \sqrt{\frac{n}{n-1}\left(\frac{\sum V^2}{n} - V_A^2\right)}$$

y = *function of wind velocity defined by the preceding equation.*

n = *number of months of April of record.*

Plotting paper is prepared on which the horizontal lines are spaced uniformly and the distance between the vertical lines is made proportional to values of y. The relationship between V_m and T will then plot as a straight line. For a value of $T = 100$, V_m equals $V_A + 3.136\ S$. Assuming that the return period of the average occurrence is equal to 2.3276 years, V_A will plot at a value of $T = 2.3276$. A straight line yielding values of V_m up to 100 years may be drawn through the plotting of V_A at $T = 2.3276$ and V_m. at $T = 100$. Observed values of V_m are plotted readily by locating the highest of record at $T = \frac{n}{1}$, the next highest at $T = \frac{n}{2}$, etc. The lowest has a value of $T = 1$, which cannot be plotted due to the nature of the coordinate system.

The above procedure was applied to maximum wind velocities for 5-minute, 1-, 3-, 6-, and 12-hour, and to 1-, 3-, 7-, and 30-day periods for April wind records available from 4 recording anemometers. It was followed also for 1-, 3-, 7-, and 30-day periods for daily wind movement records available from 8 anemometers located approximately 2 feet above the ground. In all, 67 frequency curves were derived.

RESULTS

The recurrence intervals of average maximum wind velocities occurring during the month of April for various duration periods are shown in *figures 1 through 12, pages 3 to 14*. Average velocities are given in miles per hour and the recurrence intervals in years.

Figures 1 through 4, pages 3 to 6, are for 'high' anemometers with elevations $\geq$50 feet above the ground at Manhattan, Dodge City, Wichita, and Topeka, Kans., respectively.

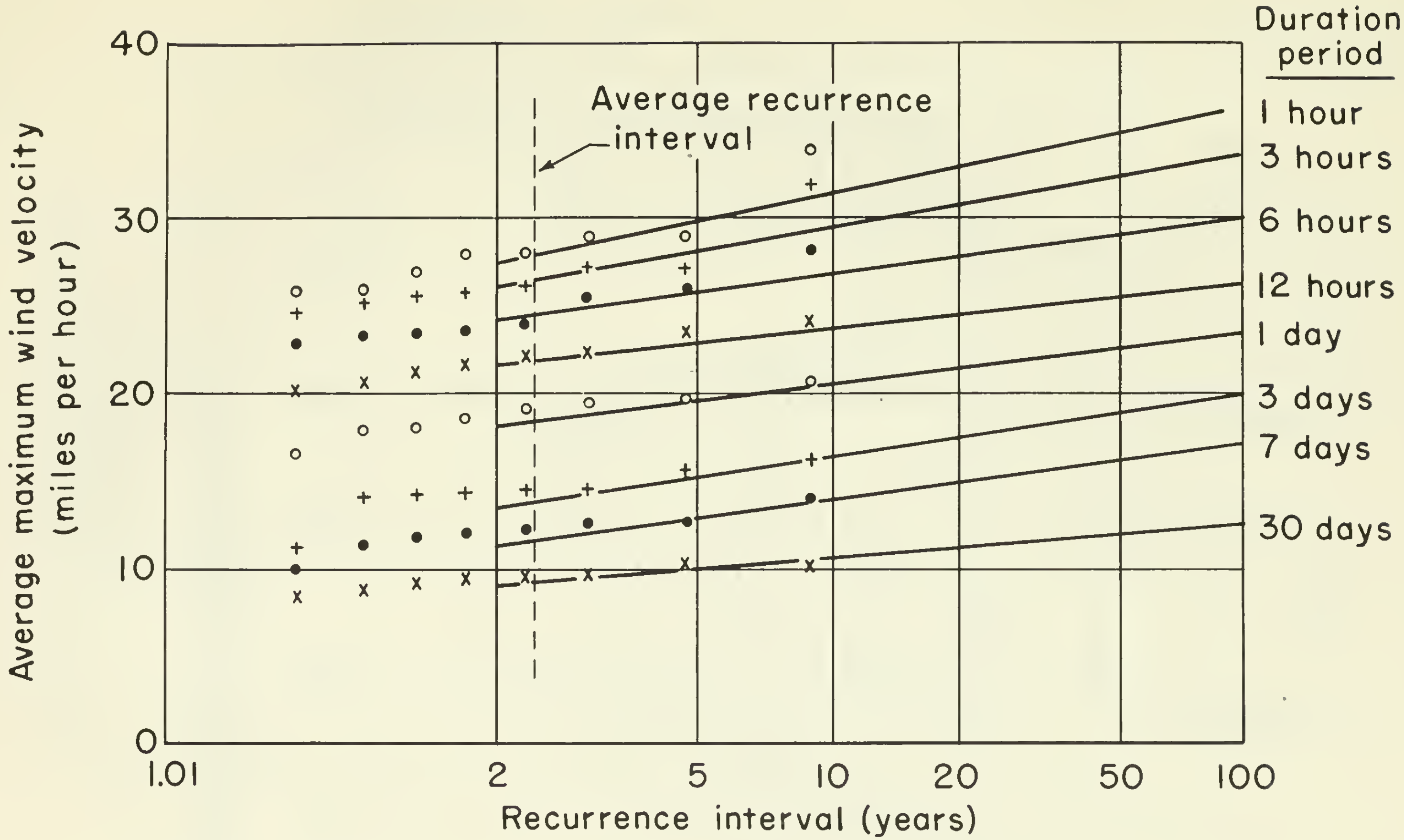

FIGURE 1.—INTENSITY-FREQUENCY DATA FOR APRIL WIND MOVEMENT AT MANHATTAN, KANSAS, 1940-48.

Gage height 50 feet. Records maintained by the Department of Physics, Kansas State College.

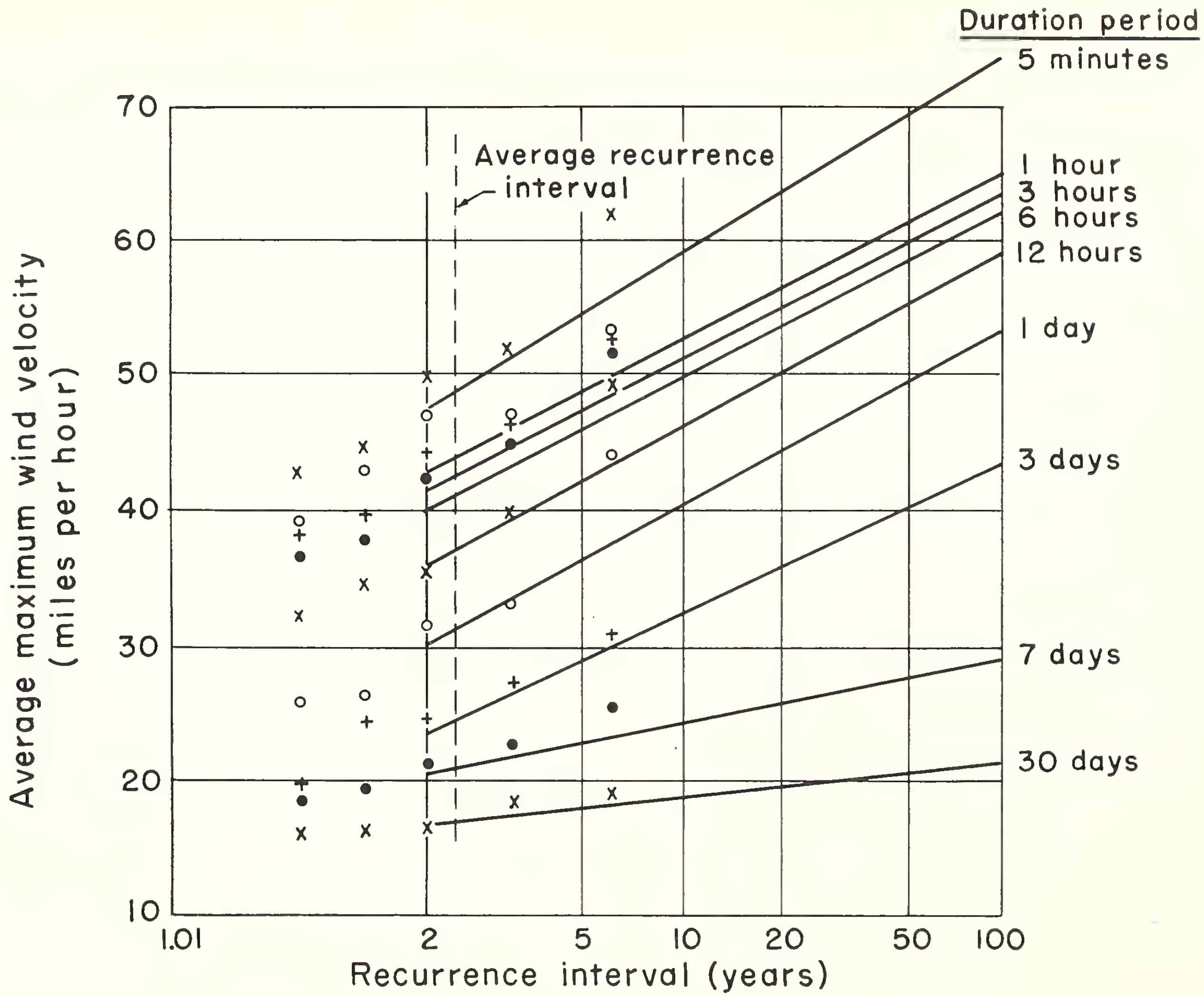

FIGURE 2.—INTENSITY-FREQUENCY DATA FOR APRIL WIND MOVEMENT AT DODGE CITY, KANSAS, 1943-48.

Gage height 58 feet. Records maintained by the U.S. Weather Bureau.

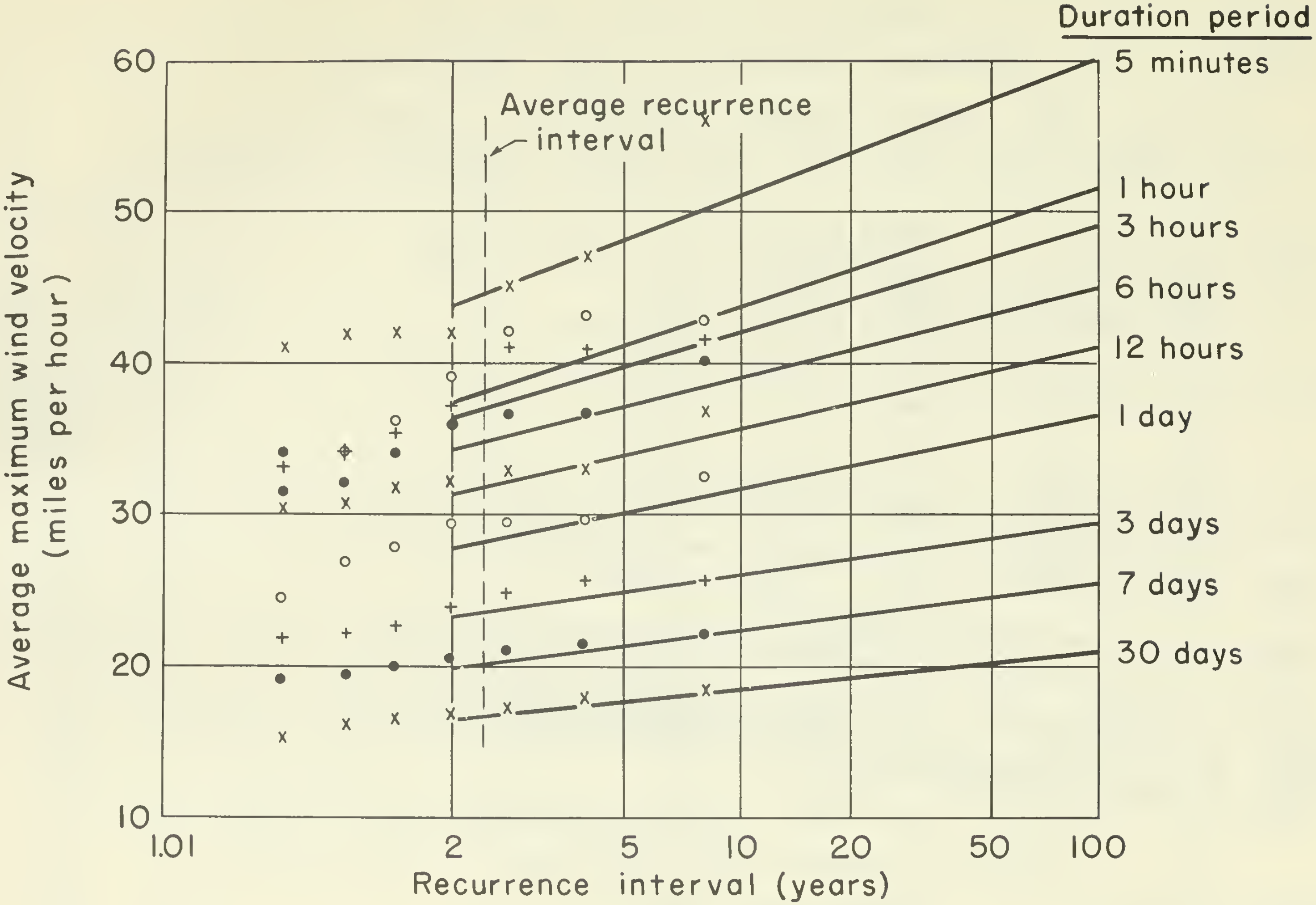

FIGURE 3.—INTENSITY-FREQUENCY DATA FOR APRIL WIND MOVEMENT AT WICHITA, KANSAS, 1941-48.

Gage height 64 feet. Records maintained by the U.S. Weather Bureau.

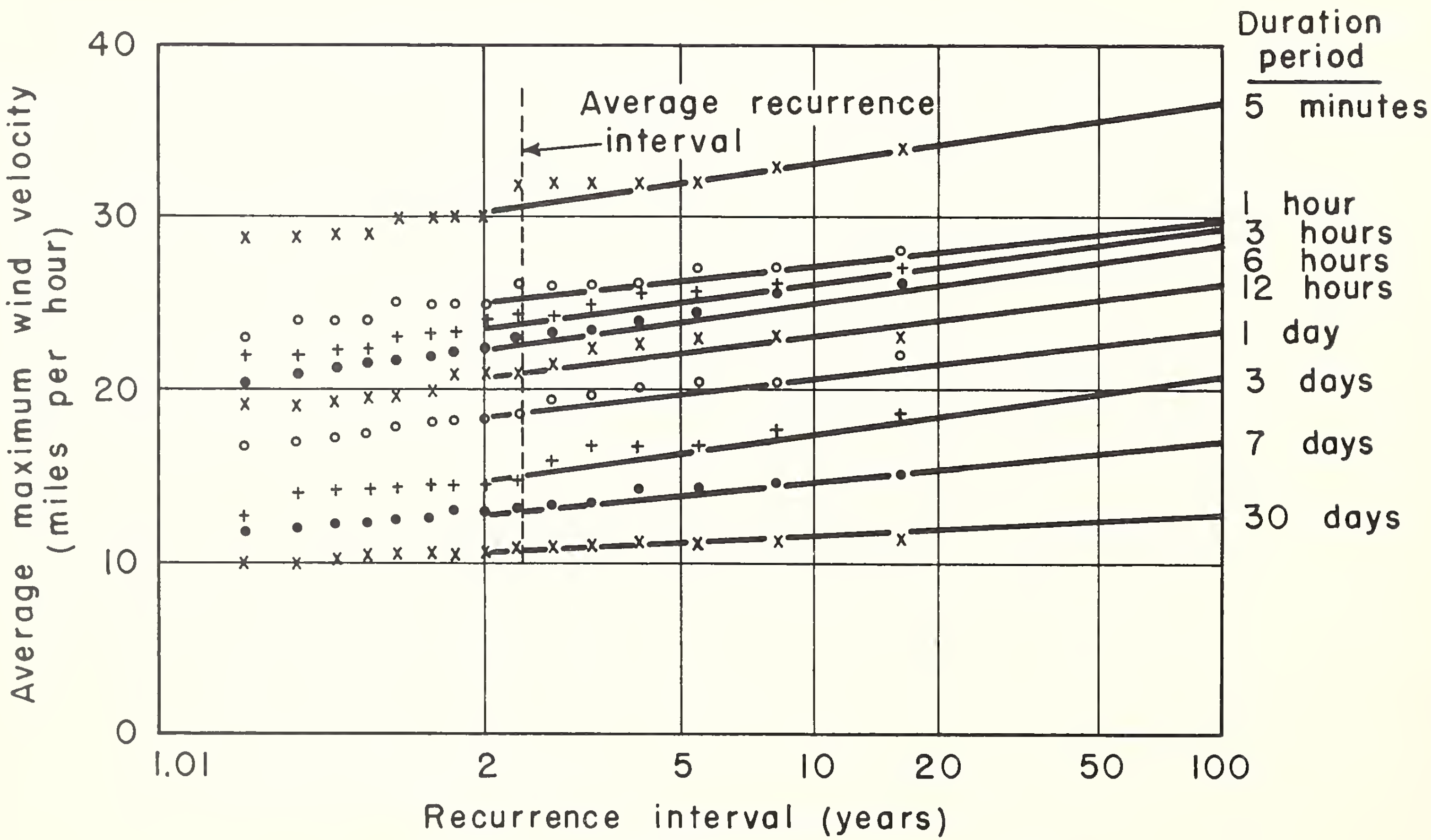

FIGURE 4. - INTENSITY-FREQUENCY DATA FOR APRIL WIND MOVEMENT AT TOPEKA, KANSAS. 1933 - 48

Gage height 89 feet. Records maintained by the U.S. Weather Bureau.

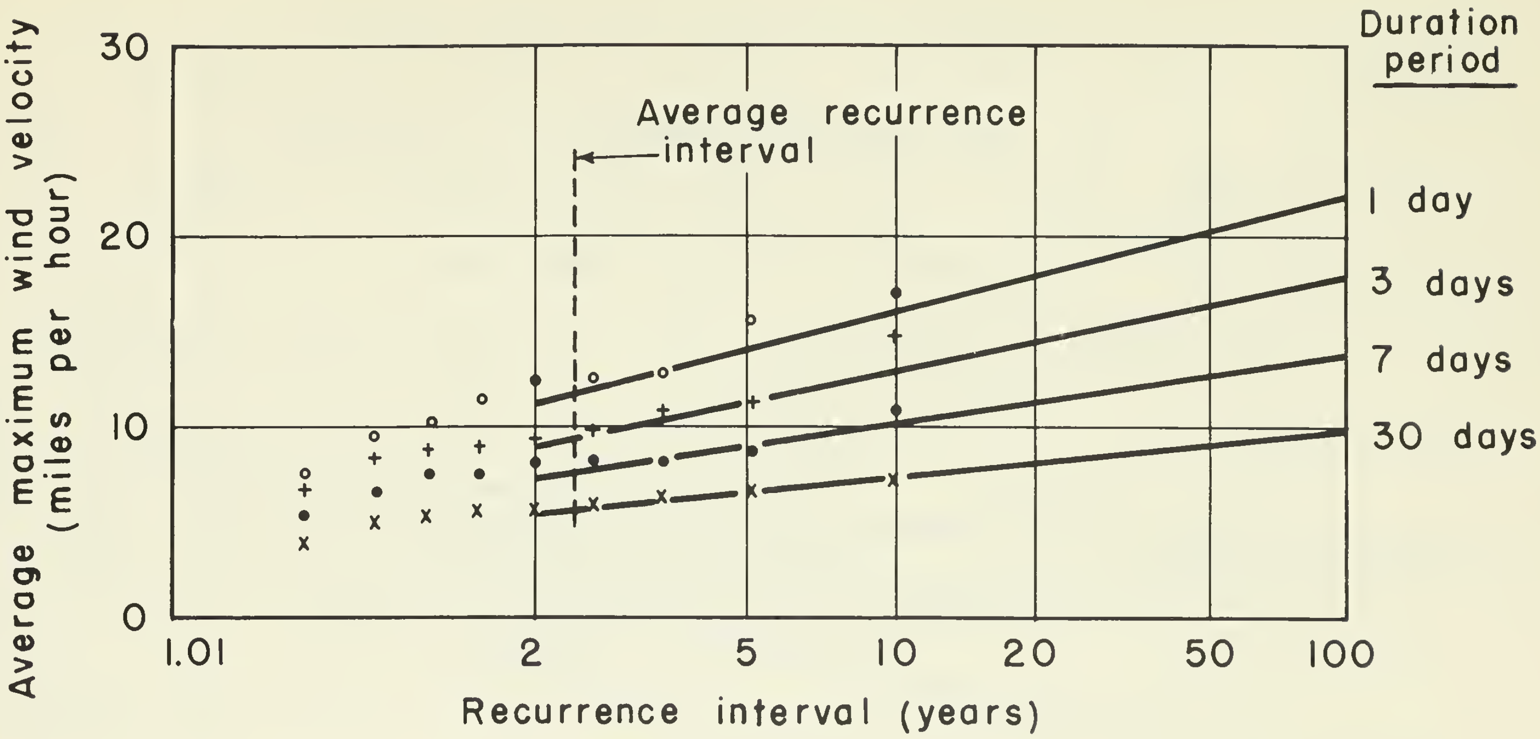

FIGURE 5. - INTENSITY - FREQUENCY DATA FOR APRIL WIND MOVEMENT AT MANHATTAN, KANSAS. 1938 — 47

Gage height 1.5 feet. Records maintained by the Department of Agronomy, Kansas State College.

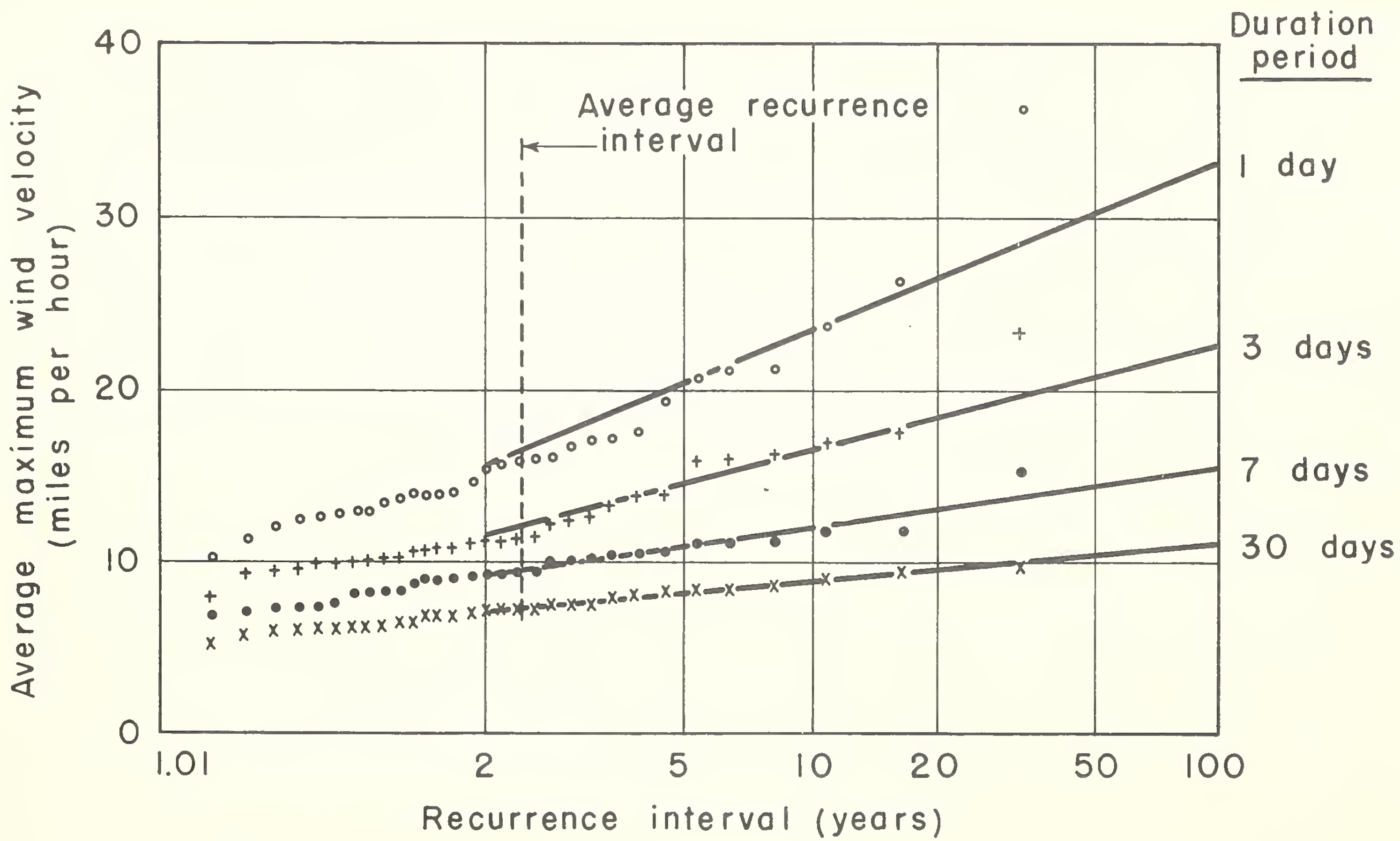

FIGURE 6. – INTENSITY – FREQUENCY DATA FOR APRIL WIND MOVEMENT AT TRIBUNE, KANSAS. 1917 — 48

Gage height 1.67 feet. Records maintained by the Kansas Agricultural Experiment Station.

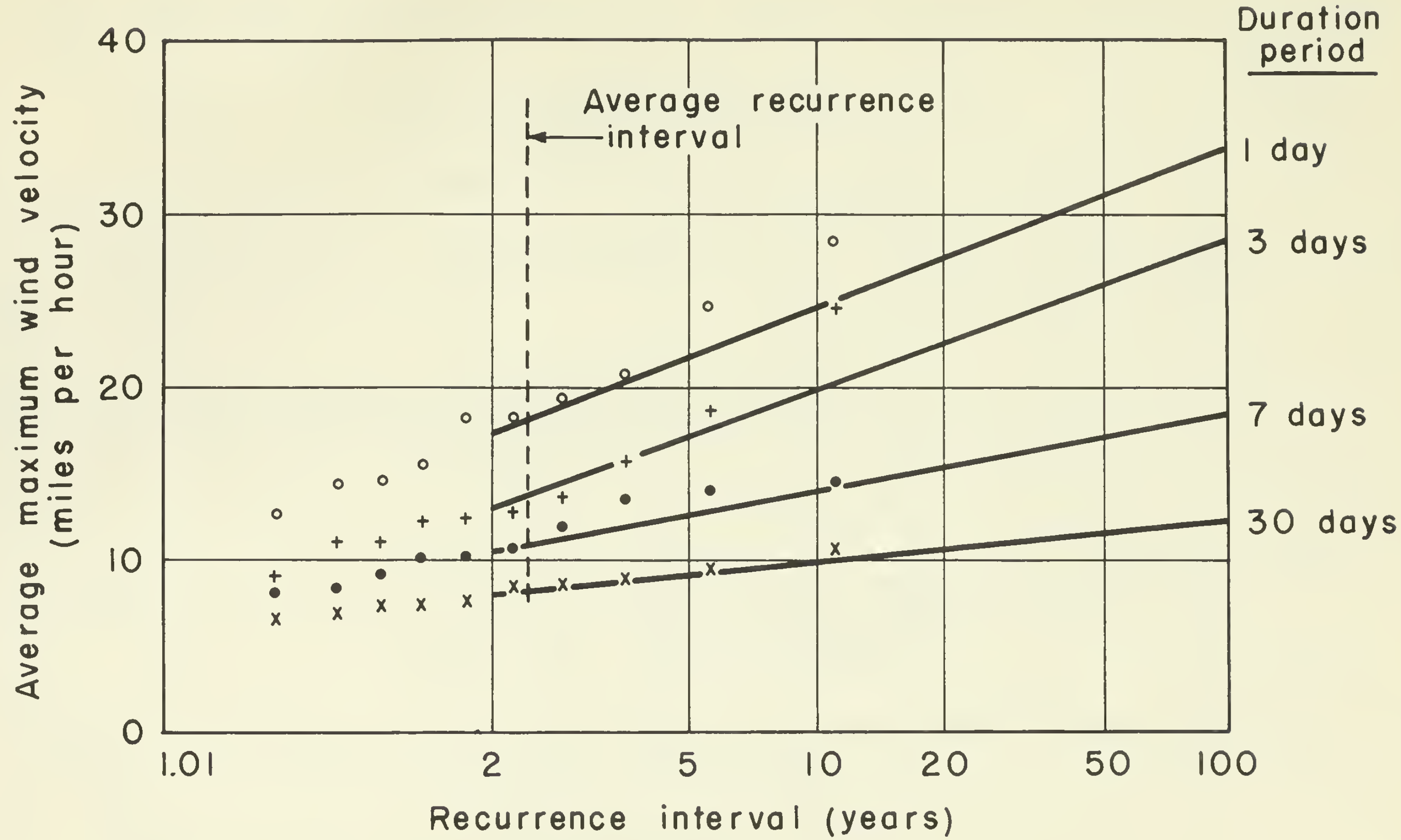

FIGURE 7. - INTENSITY-FREQUENCY DATA FOR APRIL WIND MOVEMENT AT HAYS, KANSAS. 1938 — 48

Gage height 2 feet. Records maintained by the U. S. Weather Bureau in cooperation with the Bureau of Plant Industry, Soils and Agricultural Engineering, and the Kansas Agricultural Experiment Station.

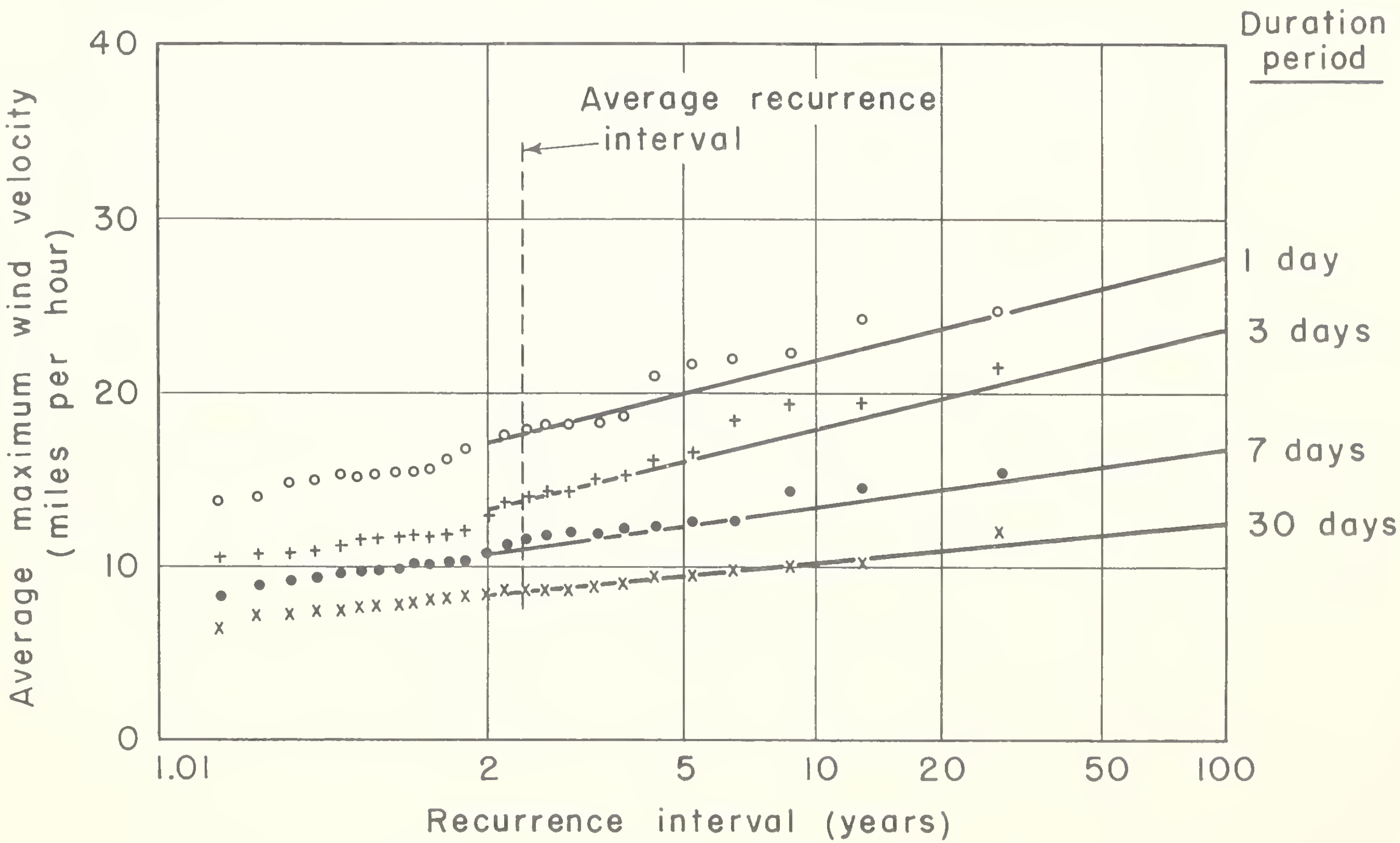

FIGURE 8. - INTENSITY-FREQUENCY DATA FOR APRIL WIND MOVEMENT AT COLBY, KANSAS. 1924 — 49

Gage height 2 feet. Records maintained by the Bureau of Plant Industry, Soils and Agricultural Engineering, and the Kansas Agricultural Experiment Station.

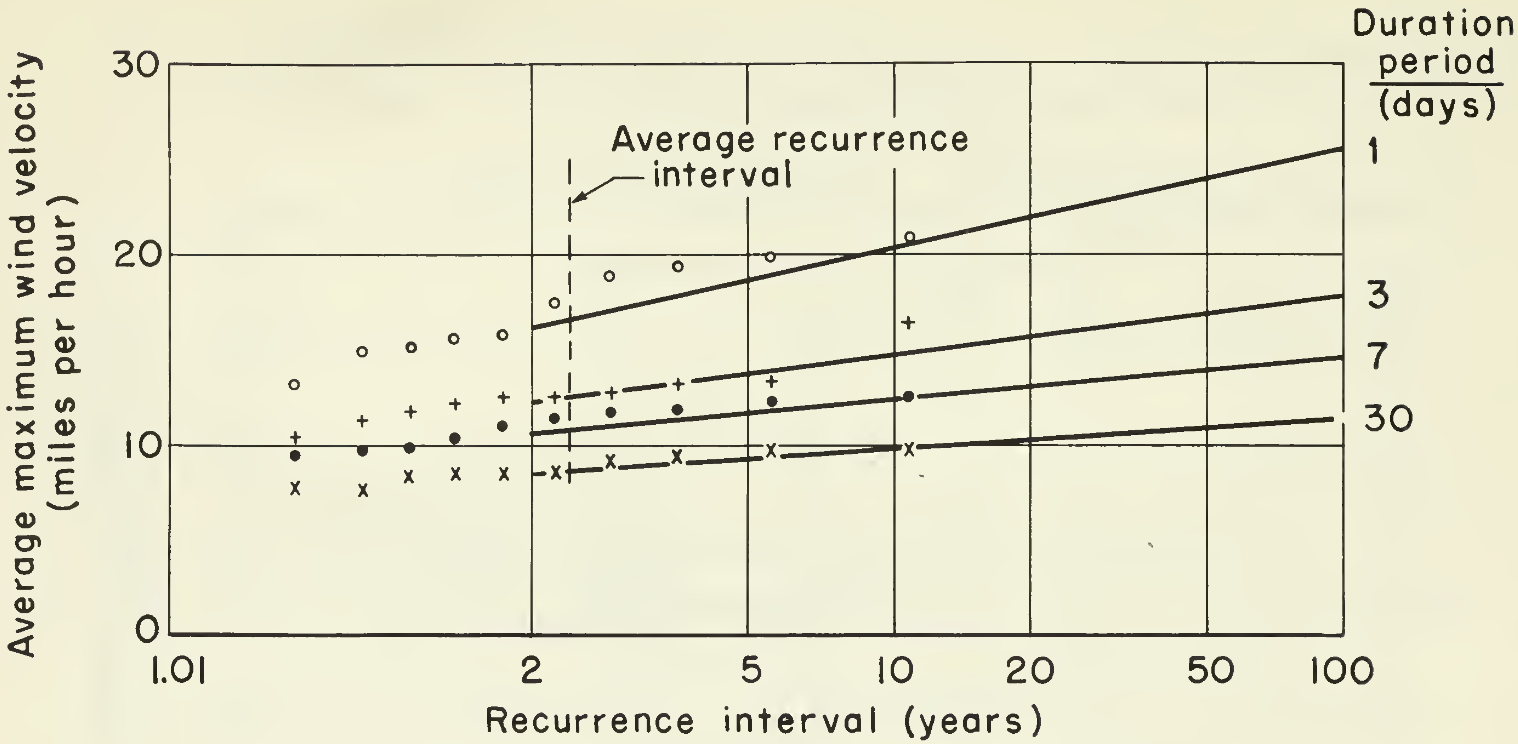

FIGURE 9.—INTENSITY-FREQUENCY DATA FOR APRIL WIND MOVEMENT AT AMARILLO, TEXAS, 1939–49.

Gage height 2.5 feet. Records maintained by the Research Division of the Soil Conservation Service.

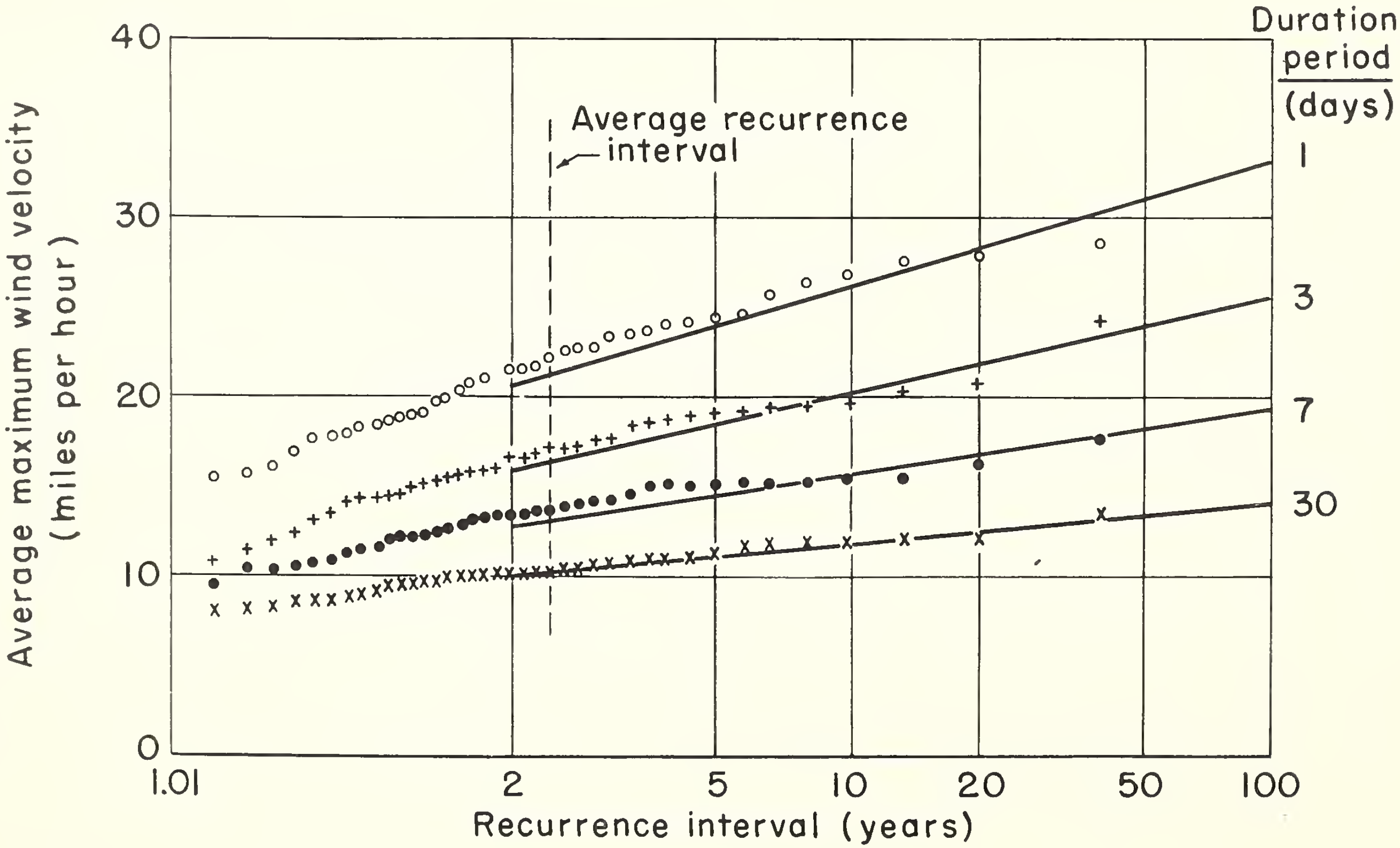

FIGURE 10.— INTENSITY-FREQUENCY DATA FOR APRIL WIND MOVEMENT AT HAYS, KANSAS, 1909–49 (except 1930)

Gage height 2 feet. Records maintained by the Bureau of Plant Industry, Soils and Agricultural Engineering, and the Kansas Agricultural Experiment Station.

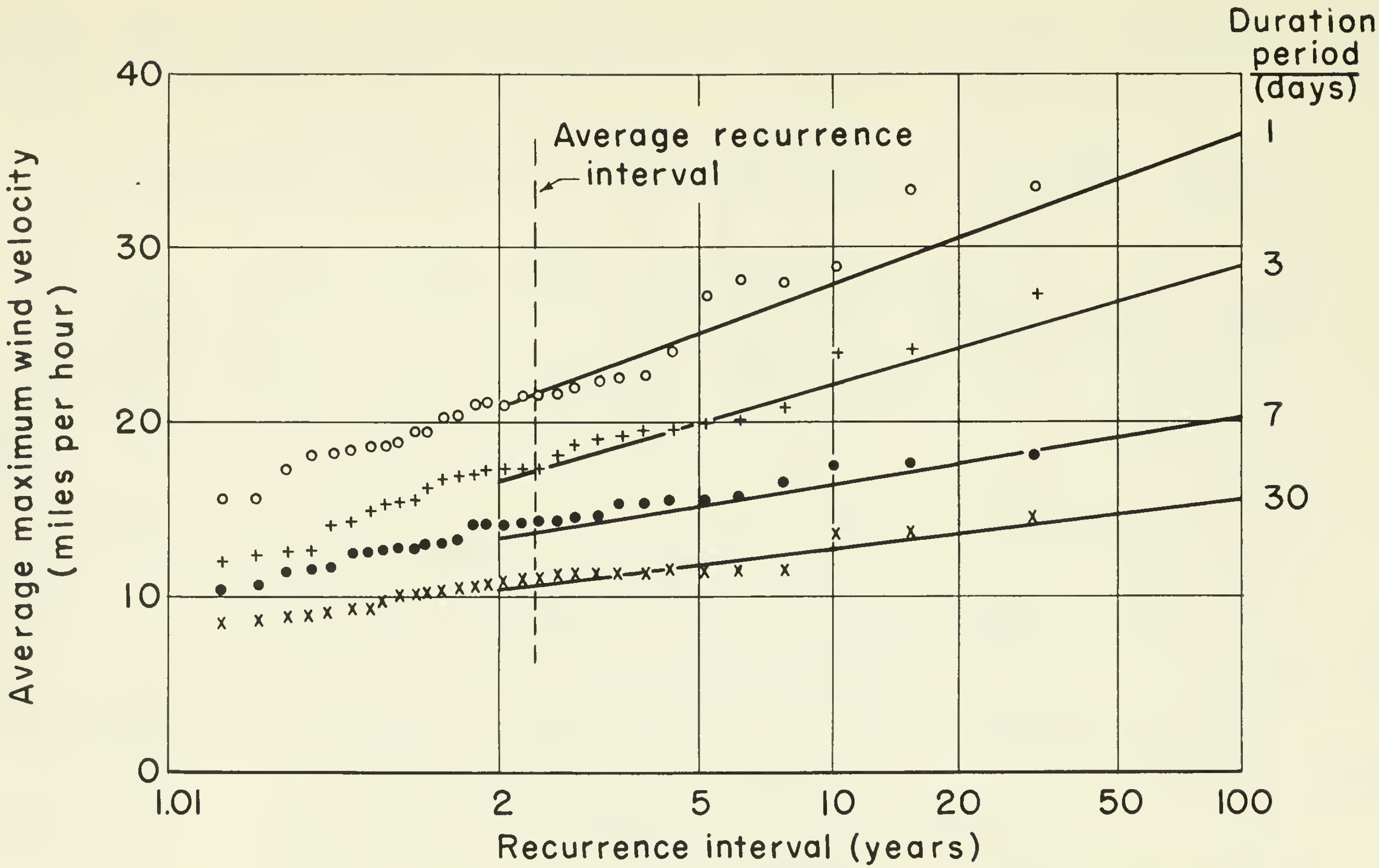

FIGURE 11.– INTENSITY-FREQUENCY DATA FOR APRIL WIND MOVEMENT AT GARDEN CITY, KANSAS, 1918–49 (except 1936)

Gage height 2.25 feet. Records maintained by the Bureau of Plant Industry, Soils and Agricultural Engineering, and the Kansas Agricultural Experiment Station.

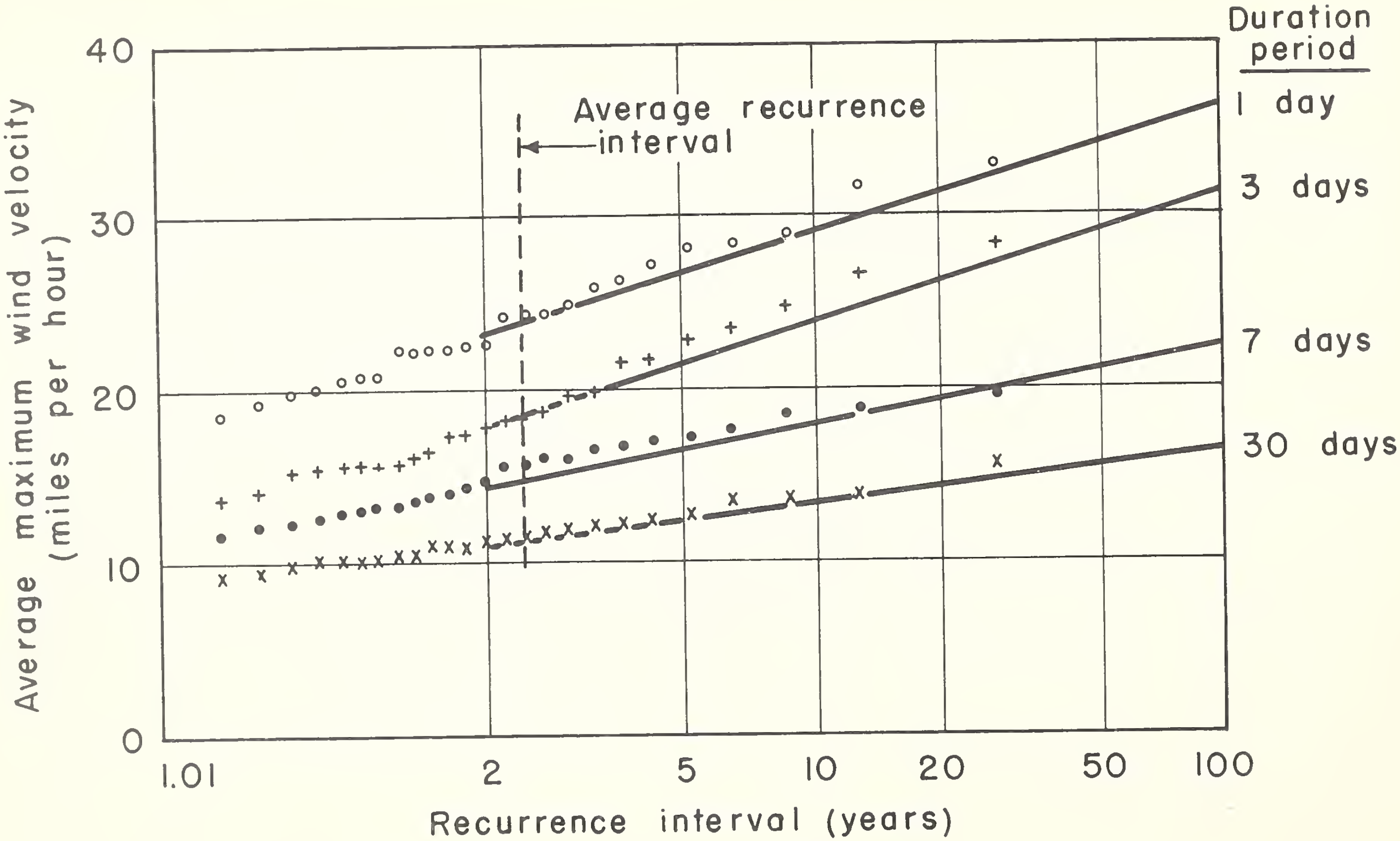

FIGURE 12. - INTENSITY-FREQUENCY DATA FOR APRIL WIND MOVEMENT AT COLBY, KANSAS. 1924 — 49

Gage height 8 feet. Records maintained by the Bureau of Plant Industry, Soils and Agricultural Engineering, and the Kansas Agricultural Experiment Station.

All frequency curves for these gages were developed from records obtained with automatic recorders.

Figures 5 through 11, pages 7 through 13, represent the frequency curves obtained for 'low' anemometers located at heights of 1.5 to 2.5 feet above the ground at Manhattan, Tribune, Hays, Colby, and Garden City, Kans.; and at Amarillo, Tex. *Figure 12, page 14,* is for a record obtained for an 8-foot height at Colby, Kans. Gage locations, approximate heights above ground, and the periods of record are given in each of the figures. Given also is the name of the agency responsible for the collection of the data. None of the 'low' anemometers were equipped with automatic recorders and the basic records consist of total wind movement as read daily.

A study of the curves in *figures 1 through 12, pages 3 to 14,* indicates that frequency methods may be used to estimate the levels of April wind movement for a given location for various duration periods. It appears further that the lines established for the several time intervals for each location approximate an expanding phenomenon with respect to the line established for the 30-day period. This fact leads to the premise that the data may be adaptable to generalization on a dimensionless basis.

DISCUSSION AND INTERPRETATION OF RESULTS

In *table 1, page 16,* are presented the ratios of wind velocity for the several duration periods to the average for the 30-day period for recurrence intervals of 2, 10, and 50 years. This ratio is V_t/V_A. It is obtained by reading values from *figures 1 through 4, pages 3 to 6,* for the 'high' anemometers. When multiplied by the average level of wind movement for the month of April at a given location, it yields the velocity as derived by the frequency curves for its appropriate duration period *(t)*. In *table 2, page 17,* comparable data for the 'low' anemometers are presented.

Inspection of the ratios V_t/V_A in *table 1, page 16,* leads to the conclusion that the higher the anemometer the less are the ratios for given recurrence intervals. Stated another way, the lower the gage the greater is the variation in wind velocity. This fact is further emphasized when the ratios secured from the 'high' anemometers, hereafter referred to as *group 1,* are compared with those for the 'low' anemometers, referred to subsequently as *group 2*. The data are, however, too meager to derive a functional relationship of the ratios to height. For this reason they will be considered here on the group basis.

Average ratios, V_t/V_A, for the records of anemometer *group 1* are shown in *table 1*. A plotting of these ratios for the various duration periods *(t)* yields the time-dimensionless intensity-frequency curves of *figure 13-A, page 18*. Comparable data for the *group 2* anemometers are given in *figure 13-B*. The solid lines represent the relationships for the data for the period from 1 to 30 days. The broken lines extending to periods of 1 hour are an estimate obtained by extrapolation. This extrapolation was made by graphical methods from the pattern established for the *group 1* locations and the relationship between the patterns for the two groups over the range of basic data common to them. They should be considered as tentative only, until such time as records become available to cover this void in present knowledge.

The average curves of *figure 13-A* are subject to a large error of estimate. For a 1-hour period, the root-mean-square of this error is approximately ± 15 percent. Their use will have meaning only within those limits.

The limitations of making reliable estimates from short-time records, as available here, or of generalizing estimates for a specific location should be recognized clearly. For example, estimates are shown for two anemometers at a height approximately 2 feet above the ground at Hays, Kans. The anemometers are located a few feet apart and are

TABLE 1.--*Average wind velocities for various duration and recurrence intervals expressed as a ratio of the 30-day average for the month of April. 'High' anemometers, 50 to 90 feet above ground elevation*

Anemometer location	Approximate height above ground	Period of record	Years of record	Monthly average (V_A)	Ratio = V_t/V_A — Duration (t): 5-min.	1-hr.	3-hr.	6-hr.	12-hr.	1-da.	3-da.	7-da.	30-da.
	Feet	*Years*	*No.*	*Mi./hr.*									
					2-YEAR RECURRENCE INTERVAL								
Manhattan	50	1940-48	9	9.3	--	2.96	2.80	2.59	2.36	1.96	1.47	1.23	0.98
Dodge City	58	1943-48	6	17.1	2.77	2.50	2.43	2.34	2.09	1.75	1.37	1.20	.99
Wichita	64	1941-48	8	16.7	2.62	2.23	2.17	2.05	1.87	1.66	1.40	1.19	.98
Topeka	89	1933-48	16	10.7	2.83	2.34	2.19	2.07	1.93	1.71	1.38	1.20	.99
Average	65		10	13.4	2.74	2.51	2.39	2.26	2.06	1.77	1.41	1.21	.99
					10-YEAR RECURRENCE INTERVAL								
Manhattan	50	1940-48	9	9.3	--	3.39	3.17	2.89	2.56	2.22	1.76	1.52	1.16
Dodge City	58	1943-48	6	17.1	3.45	3.08	3.00	2.90	2.69	2.35	1.88	1.42	1.11
Wichita	64	1941-48	8	16.7	3.06	2.61	2.51	2.34	2.13	1.89	1.56	1.34	1.11
Topeka	89	1933-48	16	10.7	3.08	2.53	2.43	2.34	2.15	1.93	1.64	1.37	1.08
Average	65		10	13.4	3.20	2.90	2.78	2.62	2.38	2.10	1.71	1.41	1.12
					50-YEAR RECURRENCE INTERVAL								
Manhattan	50	1940-48	9	9.3	--	3.76	3.49	3.13	2.75	2.44	2.04	1.76	1.30
Dodge City	58	1943-48	6	17.1	4.04	3.58	3.49	3.40	3.22	2.88	2.34	1.61	1.21
Wichita	64	1941-48	8	16.7	3.44	2.95	2.81	2.58	2.36	2.10	1.70	1.47	1.21
Topeka	89	1933-48	16	10.7	3.31	2.71	2.63	2.54	2.34	2.10	1.84	1.52	1.16
Average	65		10	13.4	3.60	3.25	3.11	2.91	2.67	2.38	1.98	1.59	1.22

TABLE 2.--*Average wind velocities for various duration and recurrence intervals expressed as a ratio of the 30-day average for the month of April. Low anemometers, 1.5 to 2.5 feet above ground elevation*

Anemometer location	Approximate height above ground	Period of record	Years of record	Monthly average (V_A)	Ratio = V_t/V_A			
					Duration (t)			
					1-da.	3-da.	7-da.	30-da.
	Feet	*Years*	*No.*	*Mi./hr.*				
					2-YEAR RECURRENCE INTERVAL			
Manhattan	1.5	1938-47	10	5.4	2.04	1.61	1.34	0.97
Tribune	1.67	1917-48	32	7.2	2.17	1.58	1.26	.97
Hays	2.0	1938-48	11	8.1	2.13	1.61	1.29	.98
Colby	2.0	1924-49	26	8.5	2.00	1.55	1.25	.98
Amarillo	2.5	1939-49	11	8.6	1.86	1.41	1.23	.97
Hays	2.0	[1]1909-49	40	10.2	2.01	1.55	1.25	.98
Garden City	2.15	[2]1918-49	31	10.7	1.96	1.56	1.25	.98
Average	2.0		23	8.4	2.02	1.55	1.27	.98
Colby	8.0	1924-49	26	11.5	2.02	1.56	1.26	.97
					10-YEAR RECURRENCE INTERVAL			
Manhattan	1.5	1938-47	10	5.4	2.95	2.37	1.87	1.35
Tribune	1.67	1917-48	32	7.2	3.24	2.28	1.65	1.22
Hays	2.0	1938-48	11	8.1	3.03	2.45	1.73	1.21
Colby	2.0	1924-49	26	8.5	2.57	2.10	1.57	1.20
Amarillo	2.5	1939-49	11	8.6	2.34	1.70	1.44	1.13
Hays	2.0	[1]1909-49	40	10.2	2.56	1.99	1.53	1.16
Garden City	2.25	[2]1918-49	31	10.7	2.62	2.07	1.53	1.19
Average	2.0		23	8.4	2.76	2.14	1.62	1.21
Colby	8.0	1924-49	26	11.5	2.52	2.08	2.56	1.18
					50-YEAR RECURRENCE INTERVAL			
Manhattan	1.5	1938-47	10	5.4	3.74	3.04	2.33	1.65
Tribune	1.67	1917-48	32	7.2	4.18	2.86	1.99	1.43
Hays	2.0	1938-48	11	8.1	3.82	3.17	2.10	1.42
Colby	2.0	1924-49	26	8.5	3.06	2.57	1.85	1.39
Amarillo	2.5	1939-49	11	8.6	2.77	1.94	1.62	1.26
Hays	2.0	[1]1909-49	40	10.2	3.04	2.35	1.79	1.31
Garden City	2.25	[2]1918-49	31	10.7	3.18	2.50	1.79	1.37
Average	2.0		23	8.4	3.40	2.63	1.92	1.40
Colby	8.0	1924-49	26	11.5	2.96	2.54	1.84	1.36

[1]Except 1930.
[2]Except 1936.

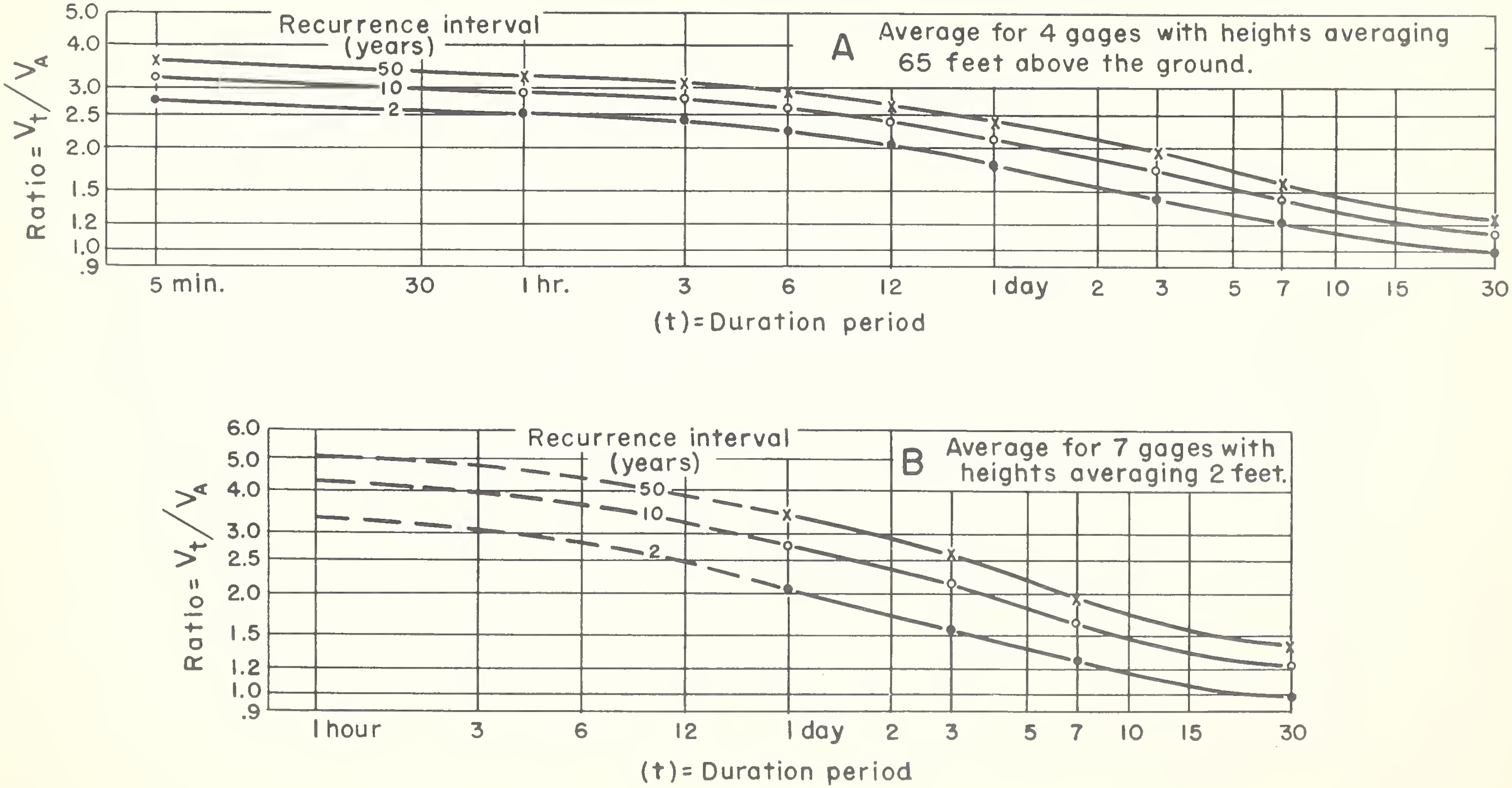

FIGURE 13.— GENERALIZED TIME-DIMENSIONLESS INTENSITY-FREQUENCY CURVES.

A For wind velocities at heights averaging 65 feet above the ground.

B For wind velocities at heights averaging 2 feet above the ground.

read by the same observer. One has an 11-year record and the other a 40-year record. The former yields an April average of 8.1 and the latter 10.2 miles per hour. This is a difference of 20 percent. It may be associated with time, environment, instrumentation, and other factors. Variations of this nature made it advisable to group the data.

It is apparent that wind velocities in eastern Kansas, as shown by records obtained at Topeka and Manhattan, are little greater than half of those experienced at comparable heights in the High Plains area.

In round figures, an average April velocity of 8.5 miles per hour at a 2-foot height appears to be applicable to the central portion of the High Plains. Twice this figure, or 17 miles per hour, is indicated for heights of approximately 60 feet. Using these figures, levels of wind movement, as calculated from the charts of *figure 13, page 18*, are shown for short-time intervals in *table 3*.

TABLE 3.--***Wind velocities in miles per hour estimated for the central portion of the High Plains region***

Duration period	Height above ground: 2 feet, Recurrence interval			Height above ground: 60 feet, Recurrence interval		
	2 years	10 years	50 years	2 years	10 years	50 years
		Miles/hour			*Miles/hour*	
1 hour	28	37	43	43	49	55
3 hours	26	33	40	41	47	53
12 hours	21	27	33	35	40	45
1 day	17	23	29	30	36	40
3 days	13	17	22	24	29	34

SUMMARY

The wind velocities experienced during the month of April at several locations in the central Great Plains region are analyzed by a simplified Gumbel method. The records from 12 anemometers were included in the study.

The results of frequency studies for specific locations and gages are shown in graphic form. These data were generalized into time-dimensionless intensity-frequency curves. Estimates were thus developed for heights averaging 65 feet above the ground for time periods varying from 5 minutes to 30 days. They were also developed from time periods varying from 1 hour to 30 days for a 2-foot height above the ground.

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